TEMPERATURE CONTROL ELEMENTS, SPINDLE ASSEMBLY, AND WAFER PROCESSING ASSEMBLY INCORPORATING SAME

BACKGROUND OF THE INVENTION

The present invention relates to wafer processing assemblies and wafer handling equipment wherein a wafer is coated or otherwise processed while supported on a rotary wafer support. There is a continuing drive in wafer processing applications, particularly in semiconductor wafer processing applications, to increase processing uniformity and accuracy. Accordingly, there is a continuing need for improved wafer processing schemes.

SUMMARY OF THE INVENTION

This need is met by the present invention wherein specialized temperature control elements, spindle assemblies, and wafer processing assemblies are provided to improve wafer processing uniformity and accuracy. In accordance with one embodiment of the present invention, a heat regulating element is provided comprising a regulating element frame defining a fluid inlet and a fluid outlet; and a fluid conduit extending from the fluid inlet to the fluid outlet. The fluid conduit defines a substantially cylindrical heat regulation void. The heat regulation void defines an inside diameter selected to accommodate an object subject to heat regulation by the heat regulating element and a circumferential gas flow path between the object and the fluid conduit.

In accordance with another embodiment of the present invention, a rotary spindle assembly is provided comprising a rotary drive motor, a rotary spindle coupled to the rotary drive motor and a heat regulating element. The heat regulating element comprises a regulating element frame defining a fluid inlet and a fluid outlet and a fluid conduit extending from the fluid inlet to the fluid outlet. The fluid conduit defines a substantially cylindrical heat regulation void. The heat regulation void defines an inside diameter selected to accommodate an outside diameter of the rotary spindle and a circumferential gas flow path between the rotary spindle and the fluid conduit.

In accordance with yet another embodiment of the present invention, a rotary spindle assembly is provided comprising a rotary drive motor, a rotary spindle coupled to the rotary drive motor, a heat regulating element, a liquid source, a temperature sensor, and a controller. The heat regulating element is arranged about the rotary spindle and comprises a regulating element frame defining a fluid inlet and a fluid outlet and a fluid conduit extending from the fluid inlet to the fluid outlet. The fluid conduit defines a substantially cylindrical heat regulation void and the heat regulation void defines an inside diameter selected to accommodate an outside diameter of the rotary spindle and a circumferential gas flow path between the rotary spindle and the fluid conduit. The liquid source is coupled to the fluid conduit and the temperature sensor is coupled to the rotary spindle assembly. The controller is coupled to the liquid source and the temperature sensor and is programmed to be responsive to a temperature signal generated by the temperature sensor.

In accordance with yet another embodiment of the present invention, a wafer processing assembly is provided comprising a rotary spindle assembly, a wafer support secured to the rotary spindle so as to be rotatable therewith, and wafer processing bowl. The rotary spindle assembly comprises a rotary drive motor, a rotary spindle coupled to the rotary drive motor, and a heat regulating element. The heat regulating element comprises a regulating element frame defining a fluid inlet, a fluid outlet, and a fluid conduit extending from the fluid inlet to the fluid outlet. The fluid conduit defines a substantially cylindrical heat regulation void, and the heat regulation void defines an inside diameter selected to accommodate an outside diameter of the rotary spindle and a circumferential gas flow path between the rotary spindle and the fluid conduit. The wafer support is secured to the rotary spindle so as to be rotatable therewith. The wafer processing bowl is arranged about the wafer support and defines an exhaust gas flow profile of the wafer processing assembly.

In accordance with yet another embodiment of the present invention, a wafer processing assembly is provided comprising a rotary spindle assembly, a liquid source, a temperature sensor, a controller, a wafer support, and a wafer processing bowl. The rotary spindle assembly comprises a rotary drive motor, a rotary spindle coupled to the

rotary drive motor, and a heat regulating element arranged about the rotary spindle and comprising a regulating element frame defining a fluid inlet, a fluid outlet, and a fluid conduit extending from the fluid inlet to the fluid outlet. The fluid conduit defines a substantially cylindrical heat regulation void and the heat regulation void defines an inside diameter selected to accommodate an outside diameter of the rotary spindle and a circumferential gas flow path between the rotary spindle and the fluid conduit. The liquid source is coupled to the fluid conduit. The temperature sensor is coupled to the rotary spindle assembly. The controller is coupled to the liquid source and the temperature sensor and is programmed to be responsive to a temperature signal generated by the temperature sensor. The wafer support is secured to the rotary spindle so as to be rotatable therewith. The wafer processing bowl is arranged about the wafer support and defines an exhaust gas flow profile of the wafer processing assembly. The dimensions of the circumferential gas flow path between the rotary spindle and the fluid conduit are selected to avoid substantial degradation of the exhaust gas flow profile.

In accordance with yet another embodiment of the present invention, a method for regulating heat generated by a rotary spindle assembly is provided comprising the steps of inputting a temperature signal generated by a temperature sensor and controlling a liquid source as a function of the temperature signal. The rotary spindle assembly comprises a rotary drive motor, a rotary spindle coupled to the rotary drive motor and a heat regulating element arranged about the rotary spindle.

In accordance with yet another embodiment of the present invention, a method of processing a wafer in a wafer processing assembly is provided comprising the steps of inputting a temperature signal generated by a temperature sensor, controlling a liquid source as a function of the temperature signal, and establishing dimensions of a circumferential gas flow path between a rotary spindle and a fluid conduit to avoid substantial degradation of a wafer processing assembly exhaust gas flow profile. The wafer processing assembly comprises a rotary spindle assembly including a heat regulating element, a wafer support secured to the rotary spindle so as to be rotatable

therewith, and a wafer processing bowl arranged about the wafer support and defining the exhaust gas flow profile of the wafer processing assembly.

In accordance with yet another embodiment of the present invention, a heat regulating flange is provided comprising an upper surface, a lower surface, a flange body defined between the upper surface and the lower surface, a passage extending through the flange body from the upper surface to the lower surface, a fluid inlet, a fluid outlet, a fluid duct defined in the flange body and extending from the fluid inlet to the fluid outlet, and a temperature sensor positioned in thermal communication with the flange body proximate the passage.

In accordance with yet another embodiment of the present invention, a rotary spindle assembly is provided comprising a rotary drive motor, a rotary spindle coupled to the rotary drive motor, and a heat regulating flange secured to the rotary drive motor. The flange comprises an upper surface, a lower surface, a flange body defined between the upper surface and the lower surface, a rotary spindle passage aligned about the rotary spindle and extending through the flange body from the upper surface to the lower surface, a fluid inlet, a fluid outlet, a fluid duct defined in the flange body and extending from the fluid inlet to the fluid outlet, and a temperature sensor positioned in thermal communication with the flange body proximate the rotary spindle passage.

In accordance with yet another embodiment of the present invention, a rotary spindle assembly is provided comprising a rotary drive motor, a rotary spindle coupled to the rotary drive motor, a heat regulating flange secured to the rotary drive motor, a liquid source, and a controller. The heat regulating flange is secured to the rotary drive motor and comprises an upper surface, a lower surface in contact with the rotary drive motor, a flange body defined between the upper surface and the lower surface, a rotary spindle passage aligned about the rotary spindle and extending through the flange body from the upper surface to the lower surface, a fluid inlet, a fluid outlet, a fluid duct defined in the flange body and extending from the fluid inlet to the fluid outlet, and a temperature sensor positioned in thermal communication with the flange body proximate the rotary spindle passage. The liquid source is coupled to the fluid duct.

The controller is coupled to the liquid source and the temperature sensor and is programmed to be responsive to a temperature signal generated by the temperature sensor.

In accordance with yet another embodiment of the present invention, a wafer processing assembly is provided comprising a rotary spindle assembly, a wafer support, and a wafer processing bowl. The rotary spindle assembly comprises a rotary drive motor, a rotary spindle coupled to the rotary drive motor, and a heat regulating flange secured to the rotary drive motor. The flange comprises an upper surface, a lower surface, a flange body defined between the upper surface and the lower surface, a rotary spindle passage aligned about the rotary spindle and extending through the flange body from the upper surface to the lower surface, a fluid inlet, a fluid outlet, a fluid duct defined in the flange body and extending from the fluid inlet to the fluid outlet, and a temperature sensor positioned in thermal communication with the flange body proximate the rotary spindle passage. The wafer support is secured to the rotary spindle so as to be rotatable therewith. The wafer processing bowl is arranged about the wafer support and defines an exhaust gas flow profile of the wafer processing assembly.

In accordance with yet another embodiment of the present invention, a wafer processing assembly is provided comprising a rotary spindle assembly, a liquid source, a controller, a wafer support, and a wafer processing bowl. The rotary spindle assembly comprises a rotary drive motor, a rotary spindle coupled to the rotary drive motor, and a heat regulating flange secured to the rotary drive motor. The flange comprises an upper surface, a lower surface in contact with the rotary drive motor, a flange body defined between the upper surface and the lower surface, a rotary spindle passage aligned about the rotary spindle and extending through the flange body from the upper surface to the lower surface, a fluid inlet, a fluid outlet, a fluid duct defined in the flange body and extending from the fluid inlet to the fluid outlet, and a temperature sensor positioned in thermal communication with the flange body proximate the rotary spindle passage. The liquid source is coupled to the fluid duct. The controller is coupled to the liquid source and the temperature sensor and is programmed to be

responsive to a temperature signal generated by the temperature sensor. The wafer support is secured to the rotary spindle so as to be rotatable therewith. The wafer processing bowl is arranged about the wafer support and defines an exhaust gas flow profile of the wafer processing assembly.

In accordance with yet another embodiment of the present invention, a method for regulating heat generated by a rotary spindle assembly is provided comprising the steps of inputting a temperature signal generated by a temperature sensor and controlling a liquid source as a function of the temperature signal. The rotary spindle assembly comprises a rotary drive motor, a rotary spindle coupled to the rotary drive motor, and a heat regulating flange secured to the rotary drive motor.

In accordance with yet another embodiment of the present invention, a method of processing a wafer in a wafer processing assembly is provided comprising the steps of inputting a temperature signal generated by a temperature sensor and controlling a liquid source as a function of the temperature signal. The wafer processing assembly comprises a rotary spindle assembly, a wafer support secured to the rotary spindle so as to be rotatable therewith, and a wafer processing bowl arranged about the wafer support, the wafer processing bowl defining an exhaust gas flow profile of the wafer processing assembly. The rotary spindle assembly comprises a rotary drive motor, a rotary spindle coupled to the rotary drive motor, and a heat regulating flange secured to the rotary drive motor.

In accordance with yet another embodiment of the present invention a rotary spindle assembly is provided comprising a rotary drive motor, a rotary spindle coupled to the rotary drive motor, a heat regulating element, and a heat regulating flange secured to the rotary drive motor.

In accordance with yet another embodiment of the present invention, a wafer processing assembly is provided comprising a rotary spindle assembly, a wafer support, and a wafer processing bowl. The rotary spindle assembly comprises a rotary drive motor, a rotary spindle coupled to the rotary drive motor, a heat regulating element, and a heat regulating flange secured to the rotary drive motor. The wafer support is secured to the rotary spindle so as to be rotatable therewith. The wafer processing

bowl is arranged about the wafer support and defines an exhaust gas flow profile of the wafer processing assembly.

Accordingly, it is an object of the present invention to provide improved heat regulation elements, spindle assemblies, and wafer processing assemblies. Other objects of the present invention will be apparent in light of the description of the invention embodied herein.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The following detailed description of the preferred embodiments of the present invention can be best understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

Fig. 1 is a schematic illustration of a wafer processing assembly incorporating a heat regulating flange according to one embodiment of the present invention;

Fig. 2 is a schematic illustration of a wafer processing assembly incorporating a wafer backside heat regulating element according to one embodiment of the present invention;

Fig. 3 is a detailed three dimensional illustration of a heat regulating flange according to one embodiment of the present invention; and

Fig. 4 is a detailed three dimensional illustration of a wafer backside heat regulating element according to one embodiment of the present invention.

DETAILED DESCRIPTION

Referring initially to Figs. 1 and 3, a wafer processing assembly **10** according to one embodiment of the present invention is illustrated. The wafer processing assembly **10** comprises a rotary spindle assembly **20**, a heat regulating flange **30**, a liquid source (illustrated schematically by arrow **40**), a controller **60**, a wafer support **70**, and a wafer processing bowl **80**. The rotary spindle assembly **20** comprises a rotary drive motor **22**, a rotary spindle **24** coupled to the rotary drive motor **22** and the heat regulating flange **30**. A wafer **75** is illustrated in a secured state, supported by the wafer support **70**. For the purposes of describing and defining the present invention, it is noted that a flange comprises and piece of hardware or hardware assembly that is arranged to be mounted to an adjacent piece of hardware or hardware assembly. The controller **60** is merely illustrated schematically and is typically merely coupled to the remainder of the assembly **10** via an electronic data connection. As is described in further detail herein, the controller **60** may comprise a control unit programmed to control motor speed and to monitor and control the temperature of various parts of the assembly **10**.

The heat regulating flange **30** is secured to the rotary drive motor **22** so as to be thermally coupled thereto. The flange **30** comprises an upper surface **31**, a lower surface **32** in contact with the rotary drive motor **22**, and a flange body **33** defined between the upper surface **31** and the lower surface **32**. A rotary spindle passage **34** is aligned about the rotary spindle **24** and extends through the flange body **33** from the upper surface **31** to the lower surface **32**. A fluid inlet **35**, a fluid outlet **36**, and a fluid duct **37** are defined in the flange body **33**. Respective input and output feed pipes **42** are provided in communication with the fluid inlet **35** and fluid outlet **36**.

Referring specifically to Fig. 3, the fluid duct **37** may be defined by machining bores in the flange body **33.** The bores are arranged such that respective perpendicular bores defining the fluid inlet **35** and the fluid outlet **36** will communicate with the bores of the fluid duct **37**. The fluid duct **37** preferably defines a closed flow path extending from the fluid inlet **35** to the fluid outlet **36.** Accordingly, in the embodiment illustrated in Fig. 3, the ends of the fluid duct **37** open to the ambient on

the periphery of the flange body **33** are preferably plugged. In this manner, the fluid duct **37** extends from the fluid inlet **35** to the fluid outlet **36** and is preferably arranged about the rotary spindle passage **34** to provide uniform regulation of the temperature of the flange body **33** relative to the passage **34**. It is contemplated by the present invention, however, that the fluid duct **37** need not surround or be symmetrical with respect to the passage **34**.

A temperature sensor **38** is positioned in thermal communication with the flange body **33** proximate the rotary spindle passage **34**, preferably by embedding the temperature sensor **38** in the flange body **33** on the side of the flange body 33 directly opposite the rotary drive motor **22**. It is contemplated by the present invention, however, that the temperature sensor may be placed in any position suitable for providing a signal indicative of the temperature of the rotary drive motor **22** and the flange body **33**, including positions remote from but in thermal communication with the flange body **33**.

In operation, the controller **60** is coupled to the liquid source **40** and the temperature sensor **38** and is programmed to be responsive to a temperature signal generated by the temperature sensor **38**. More specifically, the temperature sensor **38** provides temperature feedback from the flange body **33** to the controller **60** and may comprise a resistive thermal device, a thermocouple sensor, or any other sensor suitable to provide temperature feedback to the controller **60**. The controller **60** responds to the feedback signal by controlling the liquid supply to the fluid duct **37** so as to increase or decrease the temperature of the flange body **33** to bring it in line with a target flange body temperature. Temperature regulation may be achieved by altering the fluid flow rate through the fluid duct **37** or by altering the temperature of the fluid in the fluid duct **37**.

Referring specifically to Fig. 3, it is noted that the temperature sensor **38** may alternatively be provided in a bore **39** formed just below the lower surface **32** of the flange body **33**, as opposed to formation in a channel, as is illustrated in Figs. 1 and 2. In either case, it is often preferable to form the channel or bore as close as possible to

the lower surface 32 and to back fill the channel or bore with a conventional RTV composition.

The wafer support **70** is secured to the rotary spindle **24** so as to be rotatable therewith. The wafer processing bowl **80** is arranged about the wafer support **70** and defines an exhaust gas flow profile of the wafer processing assembly **10**. The specific arrangements of the wafer support **70** and the wafer processing bowl **80** are beyond the scope of the present invention and may be gleaned from conventional wafer processing technology. For example, U.S. Patent No. $\boxed{5,705,223,}$ the disclosure of which is incorporated herein by reference, illustrates a suitable wafer support and bowl arrangement.

Referring now to Figs. 2 and 4, a wafer processing assembly **10'** including a heat regulating flange **30** and a wafer backside heat regulating element **50** according to the present invention is illustrated. The heat regulating element **50** is arranged about the rotary spindle **24** and comprises a regulating element frame **52** defining a fluid inlet **54**, a fluid outlet **56**, and a fluid conduit **58** extending from the fluid inlet **54** to the fluid outlet **56**. The fluid conduit **58** defines a substantially cylindrical heat regulation void **55** and the heat regulation void **55** defines an inside diameter ***a***. The inside diameter ***a*** is selected to accommodate an outside diameter ***b*** of the rotary spindle **24** and a circumferential gas flow path **59** between the rotary spindle **24** and the fluid conduit **58**. The dimensions of the circumferential gas flow path **59** between the rotary spindle **24** and the fluid conduit **58** are established to ensure sufficient heat regulation and to avoid substantial degradation of the exhaust gas flow profile defined by the wafer processing bowl **80**. For example, if the spacing between the rotary spindle **24** and the fluid conduit **58** is too large temperature control will be compromised and excess gas flow moving between the rotary spindle **24** and the fluid conduit **58** will interrupt or degrade the exhaust of gasses from the interior of the bowl **80** and cause wafer contamination.

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For the purposes of describing and defining the present invention, it is noted that a spindle comprises a shaft or other cylindrical or non-cylindrical rotary drive element, the outside diameter of which is defined by its rotating cross-section. It is also noted

that heat regulating element **50** may be employed anywhere along the spindle **24** and is identified herein as a wafer backside heat regulating element merely to help describe its general location relative to the wafer support **70**.

It is noted that the circumferential gas flow path **59** and the heat regulation void **55** are substantially cylindrical but will vary from a perfect cylinder because of the presence of non-cylindrical irregularities in the flow path **59** and void **55**. For example, where the fluid conduit **58** comprises a length of spirally wound tubing, the gas flow path **59** and void **55** would be defined by the profiles of the adjacent windings of the tubing and would not define a perfect cylinder. It is also noted that the fluid inlet **54** and fluid outlet **56** of the heat regulating element frame **52** may define portion of fluid conduit itself or may merely define a passage that accommodates a tube or other fluid conduit.

In the illustrated embodiment, the regulating element frame **52** comprises a body including a cylindrical cut-out and the fluid conduit **58** comprises a length of tubing arranged about the periphery of the cylindrical cut-out. The tubing may comprise conventional PVC tubing, stainless steel tubing, or other suitable tubing material. It is contemplated by the present invention that the fluid conduit may be provided in a variety of forms other than tubing. For example, the fluid conduit may comprise a single wide passage arranged about the periphery of the cut-out.

In the illustrated embodiment, the heat regulating element frame **52** is supported by a ring chuck **51** and further defines at least one gas intake port **53** in communication with the circumferential gas flow path **59** . Gas will typically also be provided in communication with the circumferential gas flow path **59** via gaps between the heat regulating element frame **52**, the ring chuck **51**, and the rotary spindle **24**. Indeed, in some applications of the present invention, the gas intake port **53** may not be necessary to support the desired amount of flow volume in the circumferential gas flow path **59**. Alternatively, a plurality of gas intake ports **54** may be necessary. The gas may comprise air from the ambient or may be supplied by a compressed or ambient supply of inert gas.

The controller **60** may be arranged to monitor the temperature of the fluid in the fluid conduit **58** to provide an additional temperature feedback signal. In which case, it may be preferable to provide an independent fluid supply for communication with the fluid conduit **58** of the regulating element frame **52** and to control the independent fluid supply in response to the temperature feedback signal.

In operation, wafer backside heat regulating element and the heat regulating flange are utilized to stabilize the temperature of the various components of the wafer processing assembly **10**, **10'** and to make more uniform the temperature profile of a wafer subject to processing thereby. Temperature regulation is achieved by controlling the fluid supply to heat regulating flange **30**, the heat regulating element **50**, or both. For example, the controller may be programmed to alter a rate of flow of fluid through the fluid duct **37**, the fluid conduit **58**, or both, or may be programmed to alter the temperature of fluid in the fluid duct **37**, the fluid conduit **58**, or both, in response to a temperature signal generated by the temperature sensor. The present invention may incorporate a single liquid source coupled to the fluid conduit and the fluid duct or individual liquid sources coupled independently to the fluid conduit and the fluid duct.

Having described the invention in detail and by reference to preferred embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims.

What is claimed is: